

# Comparison of Brachial Artery Vasoreactivity in Elite Power Athletes and Age-Matched Controls

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## Abstract

Elite endurance athletes typically have larger arteries contributing to greater skeletal muscle blood flow, oxygen and nutrient delivery and improved physical performance. Few studies have examined structural and functional properties of arteries in power athletes.

**Purpose:** To compare the size and vasoreactivity of the brachial artery of elite power athletes to age-matched controls. It was hypothesized brachial artery diameters of athletes would be larger, have less vasodilation in response to cuff occlusion, but more constriction after a cold pressor test than age-matched controls.

**Methods:** Eight elite power athletes (age = 23 ± 2 years) and ten controls (age = 22 ± 1 yrs) were studied. High-resolution ultrasonography was used to assess brachial artery diameters at rest and following 5 minutes of forearm occlusion (Brachial Artery Flow Mediated Dilation = BAFMD) and a cold pressor test (CPT). Basic fitness measures included a handgrip test and 3-minute step test.

**Results:** Brachial arteries of athletes were larger (Athletes: 5.39 ± 1.51 vs. Controls: 3.73 ± 0.71 mm,  $p < 0.05$ ), had greater vasodilatory (BAFMD%: Athletes: 8.21 ± 1.78 vs. Controls: 5.69 ± 1.56%) and constrictor (CPT %: Athletes: -2.95 ± 1.07 vs. Controls: -1.20 ± 0.48%) responses, compared to controls. Vascular operating range (VOR = Peak dilation + Peak Constriction) was also greater in athletes (VOR: Athletes: 0.55 ± 0.15 vs. Controls: 0.25 ± 0.18 mm,  $p < 0.05$ ). Athletes had superior handgrip strength (Athletes: 55.92 ± 17.06 vs. Controls: 36.77 ± 17.06 kg,  $p < 0.05$ ) but similar heart rate responses at peak (Athletes: 123 ± 16 vs. Controls: 130 ± 25 bpm,  $p > 0.05$ ) and 1 minute recovery (Athletes: 88 ± 21 vs. Controls: 98 ± 26 bpm,  $p > 0.05$ ) following the step test.

**Conclusion:** Elite power athletes have larger brachial arteries, and greater vasoreactivity (greater vasodilatory and constrictor responses) than age-matched controls, contributing to a significantly greater VOR. These data extend the existence of an 'athlete's artery' as previously shown for elite endurance athletes to elite power athletes, and presents a hypothetical explanation for the functional significance of the 'power athlete's artery'.

**Citation:** Welsch MA, Blalock P, Credeur DP, Parish TR (2013) Comparison of Brachial Artery Vasoreactivity in Elite Power Athletes and Age-Matched Controls. PLoS ONE 8(1): e54718. doi:10.1371/journal.pone.0054718

**Editor:** Junming Yue, The University of Tennessee Health Science Center, United States of America

**Received:** September 5, 2012; **Accepted:** December 14, 2012; **Published:** January 24, 2013

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**Funding:** The authors have no support or funding to report.

**Competing Interests:** The authors have declared that no competing interests exist.

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## Introduction

In a recent review focused on the question of the characteristic 'athlete's artery', clear evidence was presented in favor of a positive influence of athletic status on arterial structure and function [1]. The authors qualified this statement to elite athletes involved in endurance sports, acknowledging a dearth in studies in elite power athletes. The major conclusion of the review was that athletes have increased conduit artery size, including enlargement of epicardial arteries and those supplying skeletal muscle [1]. It is believed arterial enlargement is associated with repetitive episodic increases in shear stress which elicit endothelium-mediated remodeling [2]. The accepted benefit of enlarged arteries in endurance athletes is greater muscle blood flow, oxygen and nutrient delivery contributing to improved performance [1], [2].

Arguably greater muscle blood flow following training may be of less consequence for elite power athletes, given the nature of their events. Given the hemodynamic responses during an acute bout of exercise in the power athlete are often quite remarkable, further study of vascular responses to a variety of stimuli is warranted [3]. For example, MacDougall et al. (1992), reported large increases in arterial blood pressure (480/350 mmHg) in subjects performing high-intensity dynamic weightlifting exercises [3]. These pressure increases are attributed to multiple factors including 1) a potent pressor response, 2) an increase in cardiac output, 3) mechanical compression of blood vessels, 4) the Valsalva maneuver and 5) the intensity of the effort [3]. It could be argued that repeated exposure to high blood pressures in power athletes could trigger vascular adaptations, such as smooth muscle hypertrophy.

Defense of arterial pressure during endurance exercise is, in part, an effort to optimize flow to the areas of high metabolic demand [4]. This defense of blood pressure is thought to be the consequence of the ability to cause vasoconstriction in larger blood vessels and loss of sympathetic control in smaller vessels [4]. The balance between sympathetic control and local demand results in a minimal level of blood flow to support a given level of muscular contraction [5]. This concept known as “sympathetic restraint” emphasizes the importance of examining the ability of a blood vessel to dilate and constrict. This may provide important information about the vessel’s “physiological” operating range, and a better understanding of the manner in which blood flow is distributed within the body during times of increased metabolic stress. Currently, little is known about the vasoconstrictor and dilator properties of conduit arteries in elite power athletes.

Vascular adaptations in elite power athletes may contribute to enhanced performance besides increasing oxygen and nutrient delivery. Of critical importance to an elite power athlete is the rapid removal of metabolites from the exercising tissue. Previous research has shown muscle fatigue characteristics are greatly improved by high flow conditions, independent of oxygen and nutrient delivery [6]. Closer examination of vasoconstrictor and dilator properties of conduit arteries may provide additional information regarding the blood flow distribution and muscular fatigue.

### Study Purpose

The purpose of this study was to examine peripheral vascular responses to vasodilatory and constrictor stimuli in elite power athletes and age-matched controls. Specifically, this study examined heart rate, blood pressure and forearm blood flow responses at rest, following occlusion and a cold pressor test. While this study cannot infer that any differences noted are a direct result of adaptation to power training, it was hypothesized that elite strength athletes would have larger brachial artery diameters at rest than untrained individuals. Based on previous literature that individuals with larger vessel diameters have less vasodilatory capacity [7], [8], it was hypothesized that elite power athletes would have lower vasodilatory capacity in response to cuff occlusion but greater vasoconstrictor responses to a cold pressor test compared to untrained individuals.

## Methods

### Study Participants

All participants were given informed consent approved by the Institutional Review Board of Louisiana State University. Participants were excluded based on signs or symptoms suggestive of disease. The main inclusion criteria for the athletes were a national or international ranking in their respective sports; and sports that primarily required high intensity, dynamic resistance training (e.g. Olympic weightlifting, powerlifting). The control subjects were recruited from the student body of the host institution. Participants were required to refrain from alcohol for 24 hours, fast for 12 hours and refrain from intense training for 12 hours prior to participating.

### Experimental Design

The study was a cross-sectional design comparing fitness profiles and vascular responses in elite strength athletes and age-matched controls. The experimental procedures consisted of basic cardio-respiratory, strength, and vascular measurements. The experimental procedures were conducted in the morning hours between 7:00 and 10:00 am, in a climate controlled room (temperature 21–

22°C), over the course of the study visit. Vascular tests were conducted first, followed by the basic fitness tests.

## Experimental Procedures

**Ultrasound measurements.** All brachial artery imaging and analyses were conducted using published guidelines [9]. Duplex Doppler-ultrasound images of the brachial artery (Toshiba Power Vision SSA-380A) were obtained with participants in the supine position using a 7.5-MHz linear array transducer prior to, during and following five minutes of forearm occlusion (**see Figure 1**). Baseline ultrasound images were obtained after 30 minutes of supine rest. All images were obtained in the longitudinal view, 3–5 cm proximal to the olecranon process, in the anterior/medial plane. Image depth was initially set at 3 cm; local gain settings were adjusted to provide optimal view of the anterior and posterior intimal surfaces of the artery and kept constant throughout. The participant’s arm was immobilized and slightly supinated.

Brachial artery flow-mediated dilation (BAFMD) was induced by forearm occlusion consisting of inflation of a pneumatic cuff (Hokanson®), positioned approximately 1 cm distal to the olecranon process, to 220 mm Hg for five minutes. The vasoconstrictor stimulus for this study was a cold pressor test (CPT) consisting of a one-minute submersion of the right hand in ice water [10], with brachial diameters being monitored for 30 seconds prior to, 1 minute during submersion and for 1 minute following removal of the hand from ice water. In addition, blood pressure and heart rate were monitored throughout the imaging process. All ultrasound images were stored for subsequent analysis.

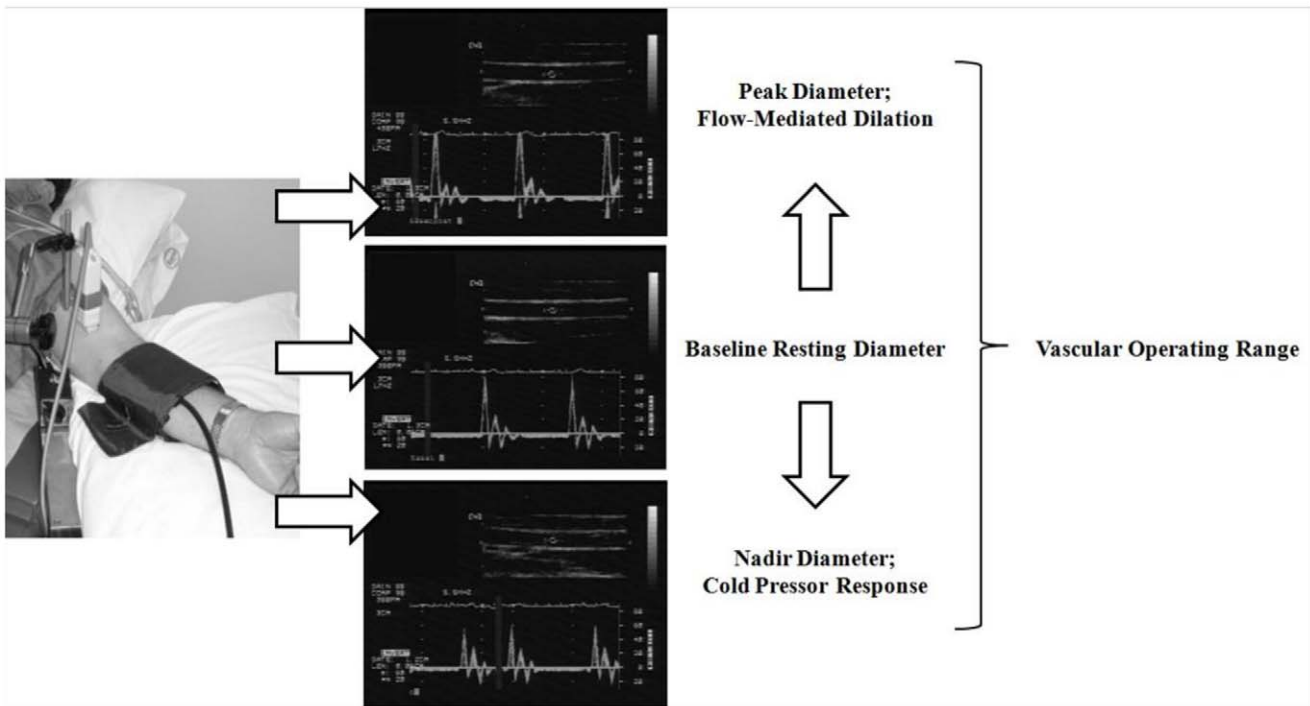
**Fitness measurements.** Height, weight and forearm circumference measurements were obtained on all participants. Hand grip strength was obtained using a hand grip dynamometer (Baseline®). The dynamometer was held at the participant’s side and the subject squeezed as hard as possible for 3 seconds and the highest value obtained was recorded. Each participant performed three trials with their left and right hands. Participants ended their visit by performing a YMCA 3-Minute step test. This test was used to provide an unbiased (i.e. both groups were not trained or overly familiar with the test) aerobic fitness measure between groups. Subjects stepped onto and off of a 12-inch (30.5-cm) bench at a rate of 24 steps/min. At the end of stepping, heart rate was taken immediately, and after every minute, for 3 minutes so that heart rate recovery could be assessed.

### Data Analysis

Brachial Imager Software (Medical Imaging Applications, LLC) was used to analyze the ultrasound images. Arterial diameters were calculated as the mean distance between the anterior and posterior wall at the blood vessel interface, with the image in diastole, defined as the peak of the R wave from the ECG signal. Base diameter (BASE) was defined by the average of 30 seconds of data obtained after 30 minutes of rest. Peak dilation (PEAK) and constriction (NADIR) were defined as the largest and smallest diameter following release of the occluding cuff and following the cold pressor test, respectively. Their values were calculated by the average of 10 images (five seconds) surrounding this highest observable peak or nadir. BAFMD was defined as the absolute (mm) and percent change in vessel diameter from BASE to PEAK. Finally, the vascular operating range was calculated as the absolute change in diameter from peak dilation to peak constriction.

### Statistical Analysis

All statistical analyses were performed using IBM SPSS statistics (version 20.0). Data are presented as mean  $\pm$  standard deviation.



**Figure 1. Vascular imaging set-up with brachial artery diameter examples after vasodilatory and constrictor stimuli, allowing estimation of the vascular operating range.**

doi:10.1371/journal.pone.0054718.g001

To compare the brachial artery dimensions, flow velocity integrals, and fitness scores of elite strength athletes and age-matched controls an independent samples T-test was performed. To determine changes in brachial diameter before and after reactive hyperemia and the cold pressor test, a repeated measure ANOVA was used. To examine the heart rate recovery following the step test a second repeated measure ANOVA was used. An alpha level of  $p < 0.05$  was required for statistical significance.

**Results**

**Participant Characteristics**

Eight nationally ranked power athletes (age =  $23 \pm 2$  years; 3 women, 5 men) and ten controls (age =  $22 \pm 1$  yrs; 4 women, 6 men) were studied. All participants were Caucasian. Participant characteristics are presented in Table 1.

**Vascular Responses**

The brachial artery diameter at rest (Athletes:  $5.39 \pm 1.51$  mm; Controls:  $3.73 \pm 0.71$  mm,  $p < 0.05$ ), peak dilation (Athletes:  $5.84 \pm 1.65$  mm; Controls:  $3.94 \pm 0.75$  mm,  $p < 0.05$ ), and in response to the cold pressor stimulus (nadir) (Athletes:  $5.29 \pm 1.52$  mm; Controls:  $3.70 \pm 0.72$  mm,  $p < 0.05$ ) are presented in **Figure 2**. The BAFMD % (Athletes:  $8.21 \pm 1.78\%$ ; Controls:  $5.69 \pm 1.56\%$ ,  $p < 0.05$ ) and percent change in diameter following CPT (Athletes:  $-2.95 \pm 1.07\%$ ; Controls:  $-1.20 \pm 0.48\%$ ,  $p < 0.05$ ) are presented in **Figure 3**. **Figure 4a and 4b** depict the brachial artery flow velocities (cm/sec) during reactive hyperemia (**Figure 4a**) and the CPT (**Figure 4b**) for the power athletes and controls. Although there were no differences in the flow velocity responses following forearm occlusion between groups, there was a tendency for the reduction in flow velocity to be greater during CPT in the athletes ( $p = 0.14$ ). In addition, the vascular operating range was significantly greater ( $p < 0.001$ ) in the athletes (0.55 mm) compared to controls (0.25 mm) (**Figure 5**). Finally, there were several associations that are noteworthy, including significant relationships between body weight and size and base diameter (BW:  $r = 0.89$ ; BMI:  $r = 0.88$ ), and vascular operating range (BW:  $r = 0.72$ ; BMI:  $r = 0.85$ ). In contrast, no significant associations were noted when using the simple ratio scaling for body weight (or mass) (i.e. artery diameter/body weight

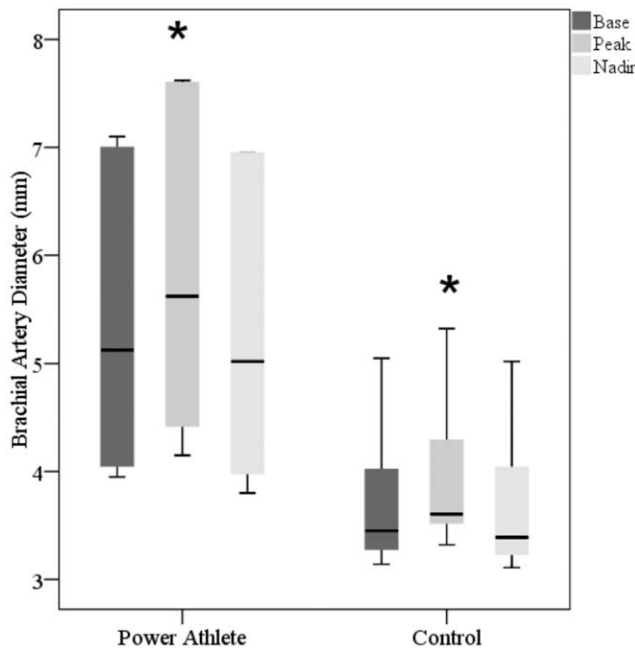
**Table 1. Participant Characteristics.**

		Minimum	Maximum	Mean	SD
Age (yrs)	Athletes	19	25	23	1.98
	Controls	20	26	22	1.42
Height (in)	Athletes	60	74	66.69	4.11
	Controls	60	74	66.4	4.14
Weight (lb)	Athletes	132	274	192.63*	45.98
	Controls	108	205	146.1	33.49
Forearm Circ. (cm)	Athletes	25.7	32.8	29.61*	2.92
	Controls	21.6	30.1	25.16	3.61
SBP rest (mmHg)	Athletes	110	150	124	12.93
	Controls	120	150	129	10.89
DBP rest (mmHg)	Athletes	70	84	79	5.52
	Controls	62	98	81	11.36
HR rest (bpm)	Athletes	55	66	62 <sup>†</sup>	4.65
	Controls	50	85	72	10.94

\* $p < 0.05$  vs. Controls;

<sup>†</sup> $p < 0.10$  vs. Controls.

doi:10.1371/journal.pone.0054718.t001

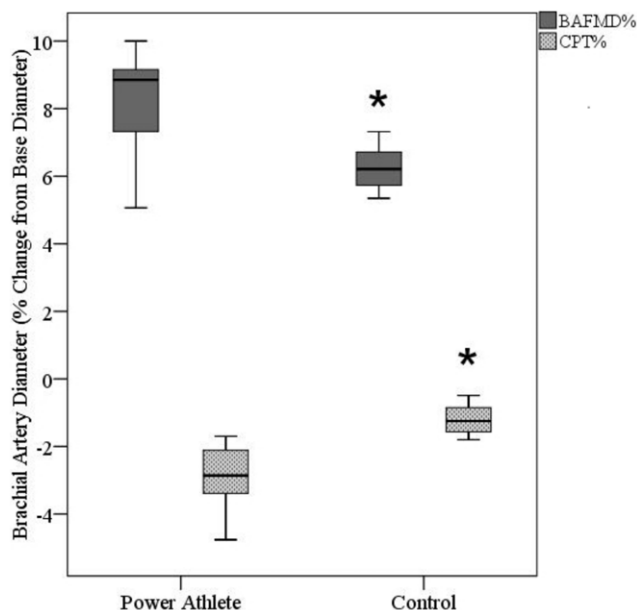


**Figure 2. Box plot of the brachial artery diameter at rest, peak dilation, and in response to the cold pressor stimulus.** \* $p < 0.05$  from baseline diameter. doi:10.1371/journal.pone.0054718.g002

(or BMI):body weight (or BMI)), or between arterial diameter and BAFMD and the percent change in the CPT response.

#### Fitness Characteristics

**Table 2** presents fitness characteristics for MVC and heart rate following the step test. Upon further examination, the decrease in



**Figure 3. Box plot for the percent change in brachial artery diameter following cuff occlusion and a cold pressor test in strength athletes and controls.** \* $p < 0.05$  from Athletes. doi:10.1371/journal.pone.0054718.g003

heart rate following the step test was not significantly different between groups.

## Discussion

This study examined brachial artery responses to a vasodilatory and constrictor stimulus in elite power athletes and control subjects. The study indicates power athletes have larger brachial artery diameters, confirming findings in endurance athletes. Uniquely, this study reports power athletes have a significant greater brachial artery vasoreactivity (combined vasodilatory and constrictor responses) compared to age-matched controls. The enhanced vasoreactivity suggests the brachial artery of power athletes has a significantly greater physiological operating range. Importantly, the greater vascular operating range in the power athletes is evident despite both groups having similar whole-body cardiorespiratory fitness measures.

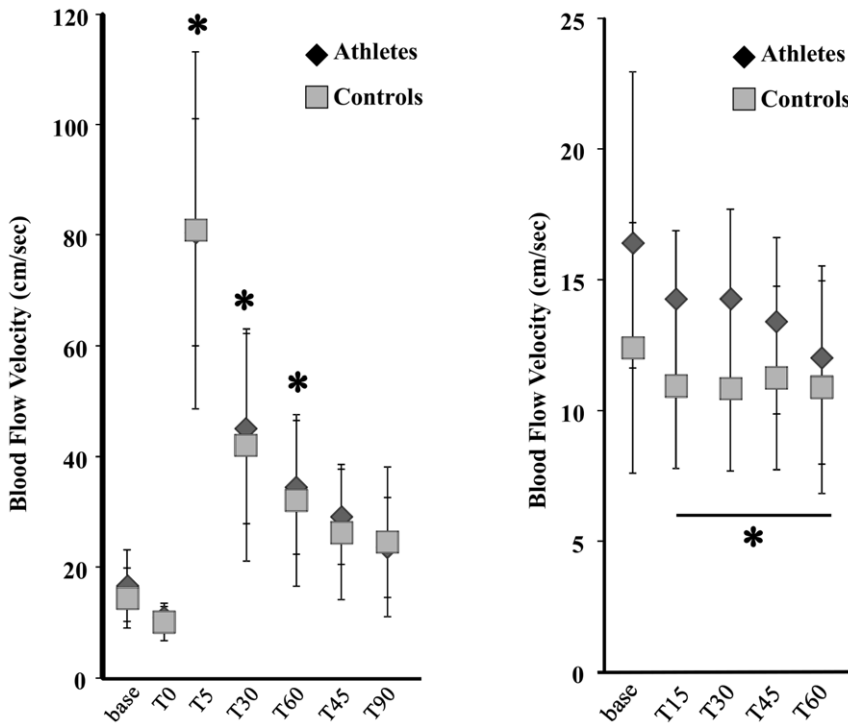
### Participant Characteristics

The power athletes included in the study had significant experience averaging approximately 6 years of competitive Olympic weightlifting, powerlifting or the hammer throw. All athletes held a national or international ranking in their respective sports. Athletes reported the majority of their training sessions consisted of heavy dynamic strength and power training with little or no emphasis on aerobic conditioning. Training duration and frequency consisted of 2–3 hours, 3–5 days/week, respectively. In contrast, the control subjects were average to above average for fitness scores in the 3-minute step test [11] and isometric handgrip strength [12].

### Brachial Artery Diameter

The present findings indicate power athletes have significantly larger resting arterial diameters compared to control subjects. This finding is consistent with previous reports in rowers [13], elite strength [14] and endurance athletes [15]. Importantly, whereas brachial artery size was significantly related to body weight and size (BMI), simple ratio scaling for body weight or mass (i.e. artery diameter/body weight (or BMI):body weight (or BMI)) removed the influence of body size variables, allowing for comparisons between groups consistent with previous reports [16]. Thus, these findings support the idea arterial size is determined by metabolic need or hemodynamic exposure. The finding that forearm circumference and handgrip strength in the power athletes was significantly greater compared to controls lends some support that the larger brachial diameter is primed to feed greater muscle mass.

This study was not designed to explore the mechanism(s) for the differences between groups but we have taken the liberty to present several possibilities that we recognize require more appropriate study designs for confirmation. First, the larger brachial artery is merely a consequence of the larger body mass of the athletes, consistent with the correlation between body mass and artery size larger arteries [16]. Second, larger arteries in the elite power athletes may reflect their somatotype, which may, in part, determine their gravitation to and success in sports with a high power component. Third, given the available evidence that report significant arterial diameter changes in situations of a reduction (e.g. as seen in paraplegics [17]) or increase (e.g. tennis players [18] in muscle mass, there is a distinct possibility of a training-induced adaptive process in the power athletes [1]. To that extent, others have proposed that repeated exercise training bouts may upregulate endogenous vasodilators (i.e. Nitric oxide) [19], which in time may give rise to arterial enlargement, in part to

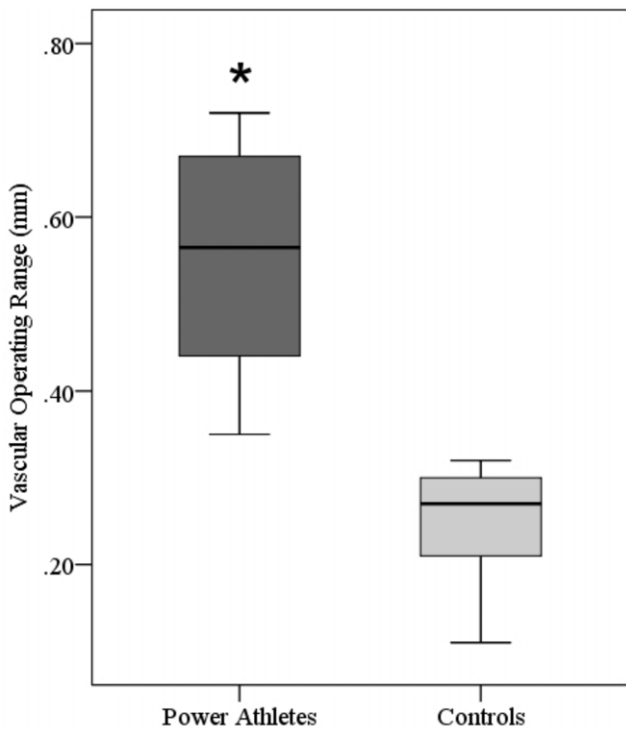


**Figure 4. Scatter plot for blood flow velocities at specific time points (sec) before (Base) and after cuff occlusion (a) and before (Base) and during the cold pressor test (b), in strength athletes and controls. \*p<0.05 vs Base.**  
doi:10.1371/journal.pone.0054718.g004

normalize shear stress [20]. In addition, arterial enlargement with training may also be pressure or neurally mediated [14].

**Brachial Artery Flow Mediated Dilation**

The magnitude of BAFMD is lower compared to previous reports from our laboratory (Allen et al.: BAFMD = 6.2±3.04; Dobrosielski et al.: BAFMD = 7.7±3.5) for control groups [21], [22]. Uniquely, the present study identifies that the elite power athletes had a significantly greater BAFMD response compared to the controls. Superior BAFMD is typically seen in elite endurance trained athletes [1]. The fact the power athletes in the present study have superior BAFMD, despite having larger vessels diameters is surprising. Typically, the vasodilatory response in a



**Figure 5. Box plot for the vascular operating range for the brachial artery following cuff occlusion and a cold pressor test in strength athletes and controls. \*p<0.05 from Controls.**  
doi:10.1371/journal.pone.0054718.g005

**Table 2. Fitness Characteristics.**

		Minimum	Maximum	Mean	SD
Hand Grip Strength (kg)	Athletes	33.67	82	55.92*	17.06
	Controls	24.33	63	36.77	14.49
Peak Exercise HR (bpm)	Athletes	100	140	123	16.25
	Controls	84	156	129.6	25.14
HR 1 Min Recovery (bpm)	Athletes	60	116	88	20.62
	Controls	52	136	97.6	26.14
HR 2 Min Recovery (bpm)	Athletes	56	108	79.5	18.69
	Controls	52	128	85.6	22.45
HR 3 Min Recovery (bpm)	Athletes	60	100	78	14.34
	Controls	56	124	81.6	21.08

\*p<0.05 vs. Controls.

doi:10.1371/journal.pone.0054718.t002

larger vessel is less than that observed in a smaller vessel [7], [8]. Whether the greater BAFMD in the elite athletes reflects a predisposition for greater responsiveness, and/or is a consequence of their training stimulus is not clear. Greater BAFMD is consistent with the belief that intermittent mechanical compressions and subsequent high shear rate on the vessel wall during the contraction and relaxation phases of muscle work up regulate nitric oxide availability and vasodilatory function [2], [8].

### Brachial Artery Vasoconstrictor Response

The present study confirms previous findings from this laboratory [23] that a cold pressor test results in a decrease in limb blood flow. The physiological mechanism contributing to a decrease in blood flow following the cold pressor test is vasoconstriction, secondary to alpha-adrenergic stimulation [24]. Previous works report an increase in heart rate and blood pressure and a decrease in blood flow to the peripheral vasculature during a cold stimulus [23], [25], [26]. Debeck et al. [27] reported an increase in muscle sympathetic nerve activity (MSNA), during cold stress, which is thought to contribute to greater vascular resistance [28]. The reduction in blood flow velocity during the cold pressor test in both the athletes and the controls confirms a sympathetic vasoconstrictor response.

The unique finding of the present study is that the power athletes exhibited a greater reduction in the brachial artery diameter to the cold pressor test than the controls. Previous studies indicate a tendency for greater muscle sympathetic nerve activity (MSNA) in younger and older endurance trained athletes [29], [30] in response to a cold pressor test. These findings indicate vigorous aerobic exercise may be associated with an enhanced MSNA response to acute stress in athletes. Again this study does not allow identification of the cause of a greater response to the cold pressor test in the power athletes. Power athletes may have a predisposition to a more responsive brachial artery, and/or the specific training stimulus may have contributed to a more sensitive artery to the cold pressor test. The functional significance of greater vasoconstriction in the brachial artery of the power athletes may be important for optimal blood flow distribution and blood pressure regulation.

### Vascular Operating Range

This study uniquely identifies that the vascular operating range is different between the athletes and controls. In fact, the vascular operating range of athletes (0.55 mm) is twofold greater than controls (0.25 mm). Again we offer the following explanation: (1) larger individuals could have a greater vascular operating range; (2) elite power athletes have a predisposition to more responsive brachial arteries; and/or (3) the specific training stimulus used by these athletes may have contributed to a more sensitive vasculature.

Recognizing the data of this study are merely observational, it is perhaps intriguing to speculate on the meaning of the differences

in vasoreactivity (greater vasodilatory and constrictor responses) between power athletes and age-matched controls. The greater vasodilatory function in the power athlete may allow greater flow through a muscular bed after a contraction for the purpose of waste-removal [6]. Paradoxically, if flow velocity and shear stress become too high, hyper perfusion and tissue damage could occur [31]. Thus, it is critical to have sympathetic restraint following a muscular contraction, in an effort to control the shear stress in the exercising region. So, whereas sympathetic restraint in endurance athletes aims to ensure that blood pressure does not fall significantly, restraint in power athletes could serve to protect against the possible dangers of extremely high flow conditions. Obviously further research is warranted to test this speculation.

### Relevance

Most previous research has focused on either a vasodilatory or constrictor stimulus to examine vascular responses. An appreciation of a physiological operating range of the brachial artery may eventually lead to the development of a more “expansive” barometer of vascular health. For example we recently reported a significant smaller vascular operating range in chronic heart failure patients compared to age-matched controls [32]. Exercise training increased the vascular operating range predominantly through an increase in vasodilatory responsiveness [32].

Importantly, this study also found significant differences in brachial artery size and responses to occlusion and a cold pressor test, and the vascular operating range between elite power athletes and age-matched controls. We believe the ability of an artery to dilate and constrict may provide important information regarding the ability to distribute blood effectively during exercise. Identification of individuals with reduced vascular operating range may eventually lead to a greater understanding of exercise intolerance.

### Conclusions

This study revealed a significantly larger brachial artery diameter at rest, and a greater magnitude of change in response to flow mediated dilation and a cold pressor test in elite power athletes compared to age-matched controls. Uniquely, this study identifies a significant greater vascular operating range in the power athletes, perhaps indicative of the athletes’ pre-disposition and/or reflective of their high intensity strength and power training regimens. These data extend the existence of an ‘athlete’s artery’ as previously shown for elite endurance athletes to elite power athletes, and presents a hypothetical explanation for the functional significance of the ‘power athlete’s artery’.

### Author Contributions

Conceived and designed the experiments: MAW DPC TRP. Performed the experiments: MAW DPC TRP PB. Analyzed the data: MAW DPC TRP PB. Wrote the paper: MAW DPC TRP PB.

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